Copy of 10

Chemistry 1154 Fall 2022 Test 3

Thursday, November 24, 2022 Time: 1 hour 50 minutes

Name: ANSWERS Student #: _____

*This test consists of **ten** pages of questions, the formula sheet, and a periodic table. Please ensure that you have a complete test and, if you do not, obtain one from me **immediately**. There are **46** marks available. Good luck!*

1) **[5 marks total]** A 2.0-litre flask was filled with 6 moles of CH_4, 2 moles of C_3H_8, and 4 moles of H_2, and the equilibrium

$3CH_4(g) \rightleftharpoons C_3H_8(g) + 2H_2(g)$ $K = 4.0$ at 601.36 K

established at 601.36 K.

a) **[1 mark]** In which direction did the reaction shift to establish equilibrium? How do you know? (No marks for guessing. 😊)

$[CH_4] = 3M$ $[C_3H_8] = 1M$ $[H_2] = 2M$ $Q = \frac{1 \times 2^2}{3^3} = \frac{4}{27}$

$Q < K$, rxn $\longrightarrow$

b) **[4 marks]** Calculate the equilibrium **partial pressures** of all species.

$3CH_4 \rightleftharpoons 2H_2 + C_3H_8$

	$3CH_4$	$\rightleftharpoons$	$2H_2$	$+$	C_3H_8
i	3		2		1
c	$-3x$		$+2x$		$+x$
e	$3-3x$		$2+2x$		$1+x$

$\frac{(2+2x)^2(1+x)}{(3-3x)^3} = 4$

$\frac{2^2(1+x)^2(1+x)}{3^3(1-x)^3} = 4$

$\frac{(1+x)^3}{(1-x)^3} = 4 \times \frac{27}{4} = 27$

$\frac{1+x}{1-x} = 3$

$1+x = 3-3x$

$2 = 4x$

$x = \frac{1}{2}$

$[CH_4] = 3 - 1.5 = 1.5$

$[H_2] = 2+1 = 3$

$[C_3H_8] = 1.5$

$RT = 0.083... \times 601.36 = 50$

$P = [] \cdot RT$, so ...

$P_{CH_4} = 75$ bar

$P_{H_2} = 150$ bar

$P_{C_3H_8} = 75$ bar

, **[5 marks total]** Butyric acid ($HC_4H_7O_2$) has a pK_a of 4.82 and, apparently, the odour of vomit. Calculate the pH of the following solutions made using butyric acid and/or its salts. All solutions were made at 25°C.

a) **[2 marks]** 0.0661 M butyric acid

$HA \rightleftharpoons H^+ + A^-$

	HA	H^+	A^-
i	0.0661	0	0
c	$-x$	$+x$	$+x$
e	$0.0661-x$	x	x

$$\frac{x^2}{0.0661-x} = 10^{-4.82}$$

$\Rightarrow x = [H^+]_e = \sim 1\times10^{-3}\ M$

$\boxed{pH = 3.0}$

b) **[3 marks]** 0.151 M potassium butyrate

$KA \rightarrow K^+ + A^-$

$A^- + H_2O \rightleftharpoons HA + OH^-$

	A^-	HA	OH^-
i	0.151	0	0
c	$-x$	$+x$	$+x$
e	$0.151-x$	x	x

$$\frac{x^2}{0.151-x} = \frac{1\times10^{-14}}{10^{-4.82}}$$

$x = [OH^-]_e = 9.98...\times10^{-6}$

$pOH = 5.0$

$pH + 5 = 14$

$\boxed{pH = 9.0}$

[10 marks total] Caffeine ($C_8H_{10}N_4O_2$) is a weak base with a $K_b = 4.1 \times 10^{-4}$ and, of course, the substance essential to my coherence at 8 AM on Mondays and Thursdays. Calculate the pH of the following solutions made using caffeine and/or its salts. All solutions were made at 5°C, where $K_w = 2.0 \times 10^{-15}$.

a) **[3 marks]** 0.98 M caffeine

$B + H_2O \rightleftharpoons BH^+ + OH^-$

i	0.98	0	0
C	$-x$	$+x$	$+x$
e	$0.98-x$	x	x

$$\frac{x^2}{0.98-x} = 4.1 \times 10^{-4}$$

$\Rightarrow [OH^-]_e = 2.0 \times 10^{-2}\ M$

$pOH = 1.6979\ldots$

$pH + pOH = 14.69897$

$\boxed{pH = 13.0}$

b) **[4 marks]** 10.0 mL of 0.99 M caffeine and 15.0 mL of 1.35 M caffeine hydrochloride

$[B] = \frac{10}{25} \times 0.99 = 0.396$

$[BHCl] = \frac{15}{25} \times 1.35 = 0.81$

$BHCl \rightarrow BH^+ + Cl^-$

0.81 0.81 0.81

$B + H_2O \rightleftharpoons BH^+ + OH^-$

0.396		0.81	0
$-x$		$+x$	$+x$
$0.396-x$		$0.81+x$	x

$$\frac{x(0.81+x)}{(0.396-x)} = 4.1 \times 10^{-4}$$

$x = [OH^-]_e = 2 \times 10^{-4}$

$pOH = 3.698$

$pH + pOH = 14.6989\ldots$

$\boxed{pH = 11.0}$

c) **[3 marks]** 0.205 M caffeine hydrochloride

$BHCl \rightarrow BH^+ + Cl^-$

0.205 0.205 0.205

$BH^+ \rightleftharpoons B + H^+$

	BH^+	B	H^+
i	0.205	0	0
c	$-x$	$+x$	$+x$
e	$0.205-x$	x	x

$$\frac{x^2}{0.205-x} = \frac{2\times10^{-15}}{9.1\times10^{-4}}$$

$$\Rightarrow x = [H^+]_e = 1\times10^{-6}$$

$$\boxed{pH = 6.0}$$

4) **[6 marks total]** Arsenic acid (H_3AsO_4) is a polyprotic acid with $K_{a1} = 6 \times 10^{-3}$, $K_{a2} = 1.1 \times 10^{-7}$, and $K_{a3} = 3 \times 10^{-12}$. It is also very toxic, and so not to be mixed with morning tea (or, really, tea at any other time of the day). Calculate the pH of the following solutions, all made using arsenic acid and/or its salts. All solutions were made at 25°C.

a) **[4 marks]** 10.0 mL of 1.0 M arsenic acid and 10.0 mL of 2.75 M NaOH

$[H_3A] = \frac{10}{20} \times 1 = 0.5\,M$

$[NaOH] = \frac{10}{20} \times 2.75 = 1.375\,M$

$NaOH \rightarrow Na^+ + OH^-$

1.375 1.375 1.375

$H_3A + OH^- \rightarrow H_2A^- + H_2O$

	0.5	1.375	0
	−0.5	−0.5	+0.5
	0	0.875	0.5

$H_2A^- + OH^- \rightarrow HA^{2-} + H_2O$

	0.5	0.875	0
	−0.5	−0.5	+0.5
	0	0.375	0.5

$HA^{2-} + OH^- \rightarrow A^{3-} + H_2O$

	0.5	0.375	0
	−0.375	−0.375	+0.375
	0.125	0	0.375

$HA^{2-} \rightleftharpoons H^+ + A^{3-}$

i	0.125	0	0.375
c	−x	+x	+x
e	0.125−x	x	0.375+x

$\frac{x(0.375+x)}{(0.125-x)} = 3 \times 10^{-12}$

$\Rightarrow x = [H^+]_e = 1 \times 10^{-12}$

$pH = 12.0$

b) **[2 marks]** 1.0 M Na_2HAsO_4

$pH = \frac{1}{2}(pK_{a2} + pK_{a3}) = 9.24$

5) **[1 mark]** A solution has a pH of 6.50. The solution is:

a) Acidic
b) Basic
c) Neutral
d) Potentially any of the above

6) **[3 marks]** A 0.250 M $HClO_4$ solution is titrated with 0.250 M KOH. Calculate the pH at the equivalence point. The titration was carried out at a temperature where $K_w = 1.0 \times 10^{-13}$. (No marks for guessing. 😊)

This is a strong acid/strong base titration. pH @ equiv. will be $\frac{1}{2}pK_w$ = **6.50**

7) **[2 marks]** Calculate the pH of a 5.00×10^{-3} M solution of $Mg(OH)_2$ at 25°C.

$Mg(OH)_2 \rightarrow Mg^{2+} + 2OH^-$

5×10^{-3} $\quad 5\times10^{-3} \quad 1\times10^{-2}$

$pOH = 2.0$

$pH + pOH = 14$

$pH = 12$

8) **[3 marks]** The indicator thymol blue begins its colour change at pH = 1.2, when the ratio $\frac{[In^-]}{[HIn]} = \frac{1}{6}$.

a) What is the pK_a for the indicator?

$10^{-1.2} \times \frac{1}{6} = 0.0105\ldots = K_{HIn}$

$\boxed{pK_{HIn} = 1.98}$

b) Thymol blue ends its colour change when the ratio $\frac{[In^-]}{[HIn]} = \frac{6}{1}$. What will be the pH of the solution at this point?

$0.0105\ldots = [H^+]_e\left(\frac{6}{1}\right)$

$\Rightarrow [H^+]_e = 1.75 \times 10^{-3} \Rightarrow pH = \boxed{2.76}$

c) Do you think this indicator would be suitable for use when titrating a weak acid with a strong base? Why or why not? (No marks for guessing. 😊)

No. At the equivalence point the solution would be basic. The end point happens while the solution is still acidic, so it's likely not a good choice.

9) **[4 marks total]** Given the following reactions:

$Ca(s) + 2C(s) \longrightarrow CaC_2(s)$ ✓	$\Delta H° = -62.8$ kJ
$2Ca(s) + O_2(g) \longrightarrow 2CaO(s)$ ✓	$\Delta H° = -1271$ kJ
$CaO(s) + H_2O(l) \longrightarrow Ca(OH)_2(aq)$ ✓	$\Delta H° = -653.1$ kJ
$2C_2H_2(g) + 5O_2(g) \longrightarrow 4CO_2(g) + 2H_2O(l)$ ✓	$\Delta H° = -2600$ kJ
$C(s) + O_2(g) \longrightarrow CO_2(g)$ ✓	$\Delta H° = -393.5$ kJ

a) **[3 marks]** Calculate $\Delta H°$ for the reaction:

$$Ca(OH)_2(aq) + C_2H_2(g) \longrightarrow CaC_2(s) + 2H_2O(l)$$

$Ca(OH)_2 \longrightarrow CaO + H_2O$ $\Delta H° = 653.1$ kJ

$C_2H_2 + 2.5O_2 \longrightarrow 2CO_2 + H_2O$ $\Delta H° = -1300$ kJ

$Ca + 2C \longrightarrow CaC_2$ $\Delta H° = -62.8$ kJ

$CaO \longrightarrow Ca + \frac{1}{2}O_2$ $\Delta H° = 635.5$ kJ

$2CO_2 \longrightarrow 2C + 2O_2$ $\Delta H° = 787$ kJ

$Ca(OH)_2 + C_2H_2 \longrightarrow CaC_2 + 2H_2O$ | $\Delta H° = 712.8$ kJ

b) **[1 mark]** What is the molar enthalpy of formation of CaO?

-635.5 kJ

$(Ca + \frac{1}{2}O_2 \longrightarrow CaO$ $\Delta H° = -635.5$ kJ)

10) **[3 marks]** Complete the table below given the reaction and the other data in the table. All work must be shown in order to receive any credit.

Compound	$\Delta H°_f$ (kJ/mol)
$NH_3(g)$	$x = -45.9$
$O_2(g)$	0
$NO(g)$	90.29
$H_2O(l)$	-285.83

$4NH_3(g) + 5O_2(g) \longrightarrow 4NO(g) + 6H_2O(l) \quad \Delta H° = -1170.22\ kJ$

$4x \quad 0 \qquad 361.16 \quad -1714.98$

-1353.82

$-1353.82 - 4x = -1170.22$

$\Rightarrow x = -45.9$

11) **[4 marks]** A sample of benzoic acid ($HC_7H_5O_2$, 122.12 g/mol) of mass 610.6 mg was burned in a bomb calorimeter with a heat capacity of 20.0 kJ/°C:

$2HC_7H_5O_2(s) + 15O_2(g) \longrightarrow 14CO_2(g) + 6H_2O(l)$

The temperature of the calorimeter rose by 0.80669°C. Calculate $\Delta H°_{298}$ for the combustion of benzoic acid.

$q_{cal} = 20.0\ \frac{kJ}{°C} \times 0.80669\ °C = 16.1338\ kJ$

$+q_{rxn} = -16.1338\ kJ$

$0\ kJ$

$610.6 \times 10^{-3}\ g \times \frac{1\ mol}{122.12\ g} \times \frac{1\ rxn}{2\ B.A.} = 0.0025\ mol\ rxn$

$\Delta E° = \frac{-16.1338\ kJ}{0.0025\ mol\ rxn} = -6453.52\ kJ$

$\Delta H° = -6453.52 + (-1)(8.3144...)(298) \times \frac{1\ kJ}{1000\ J}$

$= \boxed{-6456\ kJ}$